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Biological monitoring of exposure to perchloroethylene in dry cleaning workers

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Dry cleaning workers; perchloroethylene exposure; biological monitoring

Parole chiave
Lavoratori delle lavanderie a secco; esposizione a percloroetilene; monitoraggio biologico

Summary
Background: *Perchloroethylene (PCE) is the most widely used solvent in dry cleaning.* **Objectives:** *The aim was to evaluate PCE pollution and to identify the most reliable biological indicators for the assessment of workers' exposure.* **Methods:** *The study was performed in 40 dry cleaning shops covering a total of 71 subjects. Environmental monitoring was carried out with personal diffusive samplers (Radiello®) for the entire work shift; biological monitoring was performed by measuring PCE in urine and blood and trichloroacetic acid (TCA) in urine on Thursday evening at end-of-shift and on Friday morning pre-shift.* **Results:** *The mean concentration of PCE in air was 52.32 mg/m³, about 30% of the TLV-TWA and the mean value of the PCE in pre-shift blood samples was 0.304 mg/l, slightly more than 50% of the BEI. In dry cleaning shops employing less than 3 persons PCE in air exceeded the TLV-TWA in 7.8% of cases; the size of the shops was inversely related to pollution. Statistically significant correlations were found between PCE exposure and PCE in blood end-of-shift (r=0.67) and pre-shift (r=0.70), and PCE in urine end-of-shift (r=0.68); no correlation was found between exposure and PCE in urine pre-shift and urinary TCA.* **Conclusions:** *Dry cleaning shops still register conditions of exposure and pollution by PCE, although to a lesser extent than in the past. The most reliable indicators for biological monitoring are PCE in end-of-shift urine and PCE in blood both at end-of-shift and pre-shift at the end of the workweek.*

Riassunto
«Il monitoraggio biologico dell'esposizione a percloroetilene nei lavoratori delle lavanderie a secco». **Introduzione:** *Il percloroetilene (PCE) è il solvente maggiormente utilizzato nelle lavanderie a secco.* **Obiettivi:** *Lo scopo è stato quello di valutare l'esposizione a PCE e di identificare gli indicatori biologici più affidabili nei lavoratori esposti.* **Metodi:** *Sono state esaminate 40 lavanderie per un totale di 71 addetti. Il monitoraggio ambientale è stato effettuato con campionatore personale diffusivo (Radiello®) per l'intero turno di lavoro; il monitoraggio biologico è stato condotto misurando il PCE nel sangue e nelle urine e l'acido tricloroacetico (TCA) urinario il giovedì sera a*

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fine turno e il venerdì mattina prima del turno. **Risultati:** *La concentrazione media del PCE in aria è stata di 52,32 mg/m³, pari a circa il 30% del TLV-TWA; il valore medio del PCE nel sangue di inizio turno è risultato essere 0,304 mg/l, superiore di poco al 50% del BEI. Nelle lavanderie che occupavano meno di 3 addetti il PCE in aria ha superato il TLV-TWA nel il 7,8% dei casi; la dimensione dei locali è risultata inversamente proporzionale all'inquinamento. Correlazioni statisticamente significative sono state riscontrate tra esposizione e PCE nel sangue del giovedì sera (r=0,67) e del venerdì mattina (r=0,70), e PCE nelle urine del giovedì sera (r=0,68). L'esposizione non era invece correlata col PCE urinario di inizio turno e con il TCA urinario.* **Conclusioni:** *Nelle lavanderie a secco si registrano ancora delle condizioni di inquinamento da PCE, anche se inferiori rispetto al passato. Gli indicatori più affidabili per il monitoraggio biologico sono risultati il PCE urinario di fine turno e il PCE ematico sia di fine turno che della mattina successiva a fine settimana.*

Introduction

Perchloroethylene (PCE), which is a halogenated aliphatic hydrocarbon, was introduced in the 1940s and has become the main solvent currently used in dry cleaning (11).

The respiratory system is the main way of absorption and elimination during occupational exposure. PCE is soluble in blood and fatty tissues, but is poorly metabolized: 80-95% is in fact excreted unmodified through the respiratory airways and a small portion (1-3%) is excreted in urine as trichloroethanol (TCE), trichloroacetic acid (TCA) and as such. The half-life of PCE in blood is triphasic: 12-16 hours in phase 1, 30-40 hours in phase 2, and 55 hours in phase 3; Monster et al. reported that the concentration of PCE in blood 2 hours after exposure is 37% of that measured shortly before the end of exposure (19, 20); therefore, since the time of sampling is critical, the biological exposure indices (BEIs) of the American Conference of Governmental Industrial Hygienists (ACGIH) Commission recommends that PCE should be measured in blood at the beginning of the work shift and not at the end, when the blood marker falls rapidly.

Clinical evidence shows that exposure to PCE in humans may damage liver, kidneys and the central nervous system (24, 28, 29, 31), and also causes vision disorders (4). Exposure to high concentrations is also irritating for the eyes and upper airways (30); direct skin contact may cause burns and erythematous-squamous lesions with cracks and blisters (15, 21).

Genotoxic, mutagenic, reproductive, and carcinogenic effects of PCE are also reported (17, 22). In its latest revision, the International Agency for Research on Cancer (IARC) classified PCE under category 2A (probable human carcinogen) (14).

Environmental monitoring uses several methods of sampling and analysis, both instantaneous and throughout the work shift. In 2011, the ACGIH proposed a TLV-TWA of 170 mg/m³ (25 ppm) and a TLV-STEL (Threshold Limit Value-Short Time Exposure Level) of 675 mg/m³ (100 ppm) (2).

Several markers have been proposed for biological monitoring of PCE occupational exposure such as TCA and TCE in urine, and PCE in end-exhaled air, blood and urine. The BEIs proposed by the ACGIH for 2011 are 3 ppm of PCE in end-exhaled air and 0.5 mg/l of PCE in blood, both measured before the last shift of the workweek (2). The biological equivalent value for urinary PCE of 56 μg/l (0.056 mg/l), which corresponds to a TLV-TWA of 25 ppm, has been proposed (13). Until 2008, the ACGIH also proposed a threshold for TCA at the end of shift at the end of the workweek (3.5 mg/l), but this was then abolished in 2009.

The aim of this paper was to assess PCE exposure in a cohort of employees working in dry cleaning shops to identify the most reliable biological marker to assess occupational exposure.

Materials and methods

Study population

This study was carried out in early 2007 with environmental and biological monitoring in 40 dry cleaning shops in Padua and province (Italy), covering a total of 71 employees, 29 men and 42 women; the mean age of the workers and the mean duration of exposure to PCE were 41.3 and 15.6 years, respectively. Informed written consent to take part in the study was obtained from all subjects before enrollment.

Work cycle

The work cycle of artisan - small and industrial laundries, is usually divided into several phases:

- sort and examine articles, picking out those that may need hand spot removal or treatment of stains;
- sort articles into lots of equal weight, colours and type and load into computer-operated dry cleaning machines;
- unload the machines when the cleaning cycle is completed;
- iron and press clean articles, or send them to the finishing section;
- in the finishing section the garments are pressed by steam and vacuum.

The shops involved in our study were above all small cleaners/laundries, with less than 3 employees; only 3 had more staff and were larger shops. However, none of them had ventilation systems with specific local aspiration equipment.

The employers worked usually 8-9 hours per day, 5-6 days per week; the dry cleaning machines operated only three days per week with an average of 3.64 cycles per day. The average amount of solvent used per year was 117.22 kg (range 25-720 kg). Prevalently (72.1%) the dry cleaning machines used a closed cycle and 39 out of 40 shops had one machine, whereas the largest shop had seven machines. Manual stain removal was performed using PCE (1-2 drops) before cleaning; this operation was carried out in the same room where the machine was located. The number of manual stain removal operations was limited to 3-4 times per week in relation to the condition of the clothes.

Air monitoring

Personal monitoring

Individual exposure to PCE was assessed in all employees with the Radiello® diffusive sampler (5) for the whole working day. Sample analysis was carried out according to the method developed in our laboratory by gas chromatographic (electron capture detector) technique. Briefly, the Radiello® cartridges were eluted with 2 ml of n-hexane; after a desorption time of about 30 min, a 1 μl aliquot of the organic solution was analyzed using a HP-PONA column (length 50 m, I.D. 0.200 mm; film 0.50 μm) under the following analytical conditions: Tin j=250°C, Tdet=350°C, Tcol=60°C in isotherms for 6 min. The limit of detection (LOD) was 2 μg/l.

Istantaneous monitoring

Instantaneous measurements were also carried out, with direct reading colorimetric gas tube (Kitagawa gas detector tube system) during the most critical work phases, aimed at recording peaks of PCE pollution. The vials contained permanganate and diphenylbenzidine and react with PCE by changing colour proportionally to the quantity of PCE in the sampled air. The measuring range was 10-300 ppm with a LOD of 1 ppm. The sampling time was about 2 minutes (one pump stroke).

Biological monitoring

Blood and urine samples were taken on Thursday evening and Friday morning and PCE was measured in both biological fluids; furthermore, TCA was measured in urine. The biological indices were analyzed with the method of Christensen JM et al (6) after modification in our laboratory. Briefly, 0.2 ml of blood or 1 ml of urine were transferred into 22-ml rubber-sealed vials within 2 minutes of micturition/withdrawal, taken to a volume of 2 ml with MilliQ water, sealed immediately and

frozen until analysis. The samples were brought to room temperature and heated to 100°C in an oven for 60 min. PCE was then analyzed by gas chromatography with the headspace method and an electron capture detector in the following analytical conditions: T_{inj}=240°C, T_{det}=250°C, T_{col}=100°C in isotherms for 10 min using the column HP-PONA. The LOD were respectively 2 and 1 μg/l.

TCA in urine was measured as chloroform after thermo-decarboxylation to chloroform and carbon dioxide by transferring diluted urine into headspaced vials and heating the vials to 100°C for 60 min in accordance with the method of Senft with slight modifications (25). The chloroform was then analyzed in the same analytical conditions described for PCE in blood and urine. Calibration curves were prepared by the method of standard additions of urine or blood from a subject not exposed to chlorides. The LOD was 10 μg/l.

Statistical analysis

Statistical analysis was carried out using the StatsDirect statistical software (Statsdirect 2.7.7 version, Statsdirect Ltd, UK). Evaluation between environmental data and biological variables was performed by means of linear regression analysis and calculation of r correlation coefficient. In all tests, a p value lower than 0.05 (two-tailed) was considered as statistically significant.

Results

Table 1 lists environmental exposure levels and biological marker values in the examined subjects.

The mean concentration of PCE in air was 52.32 mg/m^3, about 30% of the current TLV-TWA of 170 mg/m^3. Single values revealed that the threshold had been exceeded in 4 out of 71 cases. The mean value of PCE in pre-shift blood samples was 0.304 mg/l, slightly more than 50% of the ACGIH BEI; also PCE in urine at end-of-shift was on average 50% of the biological threshold of 0.056 mg/l proposed in the literature (13); on the contrary TCA in urine at end-of-shift was, on average, higher than the ACGIH BEI adopted until 2008.

Tables 2 and 3 show the results according to the number of workers per dry cleaning shop and the size of the shop, respectively. Most of the shops were family-operated and employed less than 3 persons. In these shops, 7.8% of cases exceeded the TLV-TWA and 25.5% the BEI for PCE in blood,

Table 1 - Values of PCE exposure in 71 subjects occupationally exposed in dry cleaning shops

Markers	Mean	Median	SD	range
PCE in air (mg/m^3) (personal exposure on Thursday)	52.32	34.89	59.49	0.48-284.54
PCE in blood (mg/l) end-shift (Thursday evening)	0.617	0.453	0.519	0.038-1.943
PCE in blood (mg/l) pre-shift (Friday morning)	0.304	0.266	0.258	0.019-1.407
PCE in urine (mg/l) end-shift (Thursday evening)	0.024	0.015	0.025	0.003-0.128
PCE in urine (mg/l) pre-shift (Friday morning)	0.012	0.010	0.008	0.001-0.048
TCA in urine (mg/l) end-shift (Thursday evening)	4.07	2.60	6.16	0.41-49.65
TCA in urine (mg/l) pre-shift (Friday morning)	5.88	3.73	8.62	0.61-65.97

Table 2 - Characteristics of PCE exposure according to number of workers in dry cleaning shops

	N° dry cleaning shops	N° employees	% employees exceeding TLV-TWA (170 mg/m^3)	% employees exceeding BEI of PCE in blood pre-shift (0.5 mg/l)
1-3 employees	37	50	7.8	25.5
More than 3 employees	3	21	0	0

Table 3 - PCE concentrations in environment, blood and urine, according to the size of dry cleaning shops

	PCE in air (mg/m^3)	PCE in blood pre-shift (mg/l)	PCE in urine end-shift (mg/l)
≤50 m^2 (N° of subjects 18)			
Mean	91.08	0.437	0.042
Median	67.27	0.362	0.026
Geom. mean	68.83	0.361	0.032
St. deviation	70.37	0.297	0.033
51-100 m^2 (N° of subjects 22)			
Mean	38.30	0.307	0.017
Median	31.84	0.246	0.014
Geom. mean	24.54	0.210	0.013
St. deviation	42.85	0.220	0.016
>100 m^2 (N° of subjects 31)			
Mean	26.06	0.173	0.013
Median	8.84	0.121	0.010
Geom. mean	13.83	0.093	0.011
St. deviation	29.34	0.175	0.008

while in the bigger shops with more than 3 employees the threshold values were never exceeded. In particular, table 3 shows the influence of shop size (area) in PCE exposure: exposure in small shops (≤50 m^2) showed values inversely proportional with area, from 91.08 mg/m^3 in shops of <50 m^2 to 38.30 mg/m^3 in those measuring between 51 and 100 m^2, and 26.06 mg/m^3 in larger ones (>100 m^2). Similar results were found for PCE in pre-shift blood, which was slightly under the ACGIH threshold (0.437 mg/l) in the smallest shops, fell to 0.307 mg/l in medium-sized shops, and to less than half, 0.173 mg/l, in the largest ones; the same trend was observed for PCE in urine at end-of-shift.

Table 4 shows PCE concentrations determined with the colorimetric tube method during the most critical work phases, in which PCE reaches the peak: the data show that the periods of greatest risk are those when the dry-cleaning machines are opened and unloaded, with concentrations exceeding 100 ppm. The solvent peaks are short: about 5 min after the end of unloading, the level of environmental PCE falls to 35 ppm. Taking in account the time used to open and unload the washing machine (10-15 minutes), it is possible that exposure to PCE during these phases is close to the TLV-STEL. Dry cleaning operations involve smaller peaks, never exceeding 50 ppm (maximum value 40 ppm) and which rapidly decrease to 6 ppm after 5 minutes. Mild concentrations are measured in the air above the baskets containing clothes, blankets, etc just cleaned and unloaded from the machines, although high values were found in some cases (maximum value 80 ppm).

Table 4 - Peaks of pollution of PCE (in ppm) in some work phases

Work phase	PCE in ppm
- Manual stain removal	25-40
- 5 min after end of manual stain removal	6
- Machine loading	18
- Machine opening	141-300
- Machine unloading	53-180
- 5 min after end of unloading	35
- In air above baskets of unloaded clothes	15-80

Table 5 reports the correlations (equation, correlation coefficient and statistical significance) between environmental and biological indices of PCE exposure in the dry cleaning workers under study; figures 1-5 show the statistically significant

Table 5 - Equation, correlation coefficient and statistical significance among environmental (PCE in air) and biological indices (PCE in blood and in urine, TCA in urine) of exposure to PCE in dry cleaning workers examined

	Equation	r	p
PCE in air vs PCE in blood end-shift	y=0.29528 + 0.00596 x	0.68	p<0.001
PCE in air vs PCE in blood pre-shift	y=0.14517 + 0.00303 x	0.70	p<0.001
PCE in air vs PCE in urine end-shift	y=0.00874 + 0.00029 x	0.68	p<0.001
PCE in air vs PCE in urine pre-shift	y=0.01071 + 0.00003 x	0.27	n.s.
PCE in air vs TCA in urine end-shift	y=3.03964 + 0.01896 x	0.18	n.s.
PCE in air vs TCA pre-shift	y=5.87547 + 0.00002 x	0.00012	n.s.
PCE in blood at end-shift vs PCE in urine end-shift	y= 0.00260 + 0.03450 x	0.72	p<0.001
PCE in blood pre-shift vs PCE in urine pre-shift	y= 0.00976 + 0.00933 x	0.31	n.s.
PCE in blood pre-shift vs PCE in urine end-shift	y= 0.00677 + 0.05596 x	0.58	p<0.001

n.s.: not significant

correlations: PCE levels in blood on Thursday evening (r=0.67) and on Friday morning (r=0.70), and PCE in urine on Thursday evening (r=0.68) were found to be well correlated with exposure (p<0.001 for all); for an exposure corresponding to the TLV of 170 mg/m^3, biological equivalent values of 1.308 mg/l for PCE in end-shift blood, of 0.660 mg/l for PCE in pre-shift blood, and of 0.058 mg/l for PCE in end-shift urine were calculated based on equation data of table 5.

In contrast, there were no correlations between PCE in air and in urine on Friday morning and between PCE in air and end-of-shift and pre-shift TCA in urine. Furthermore, statistically significant

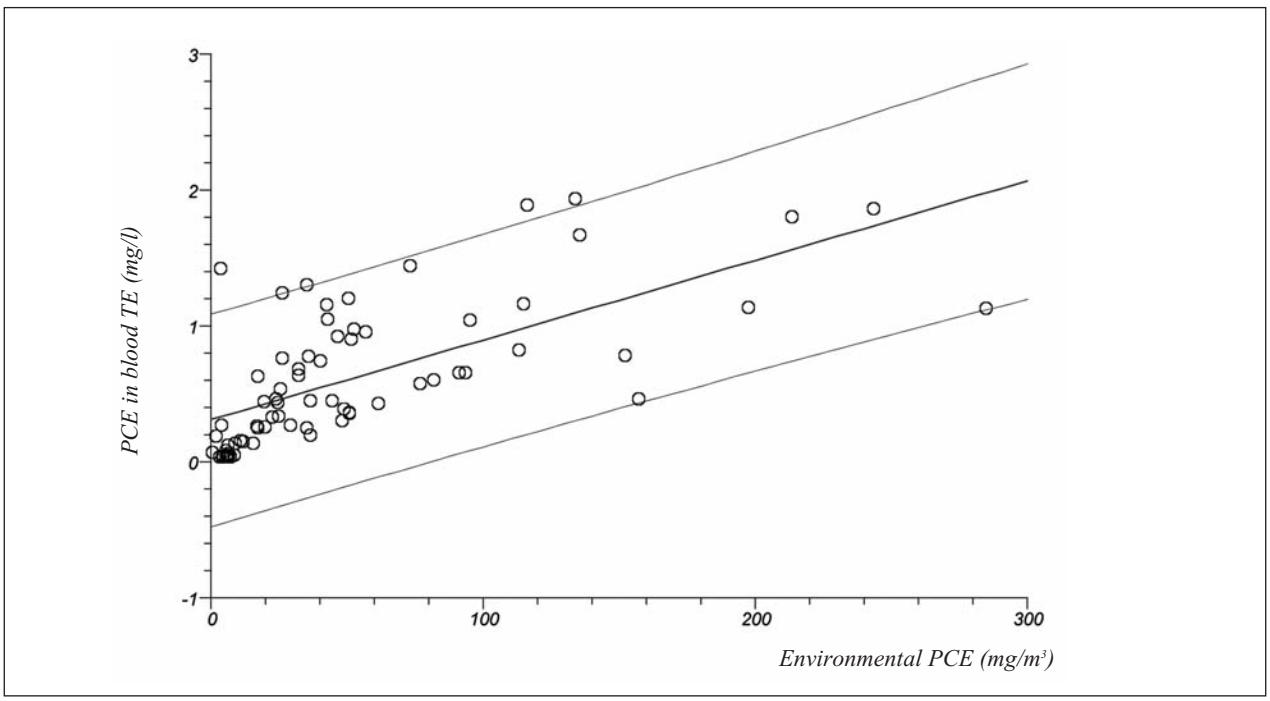

Figure 1 - Correlation between PCE in blood (mg/l) on Thursday evening (TE) and environmental exposure to PCE (mg/m^3)

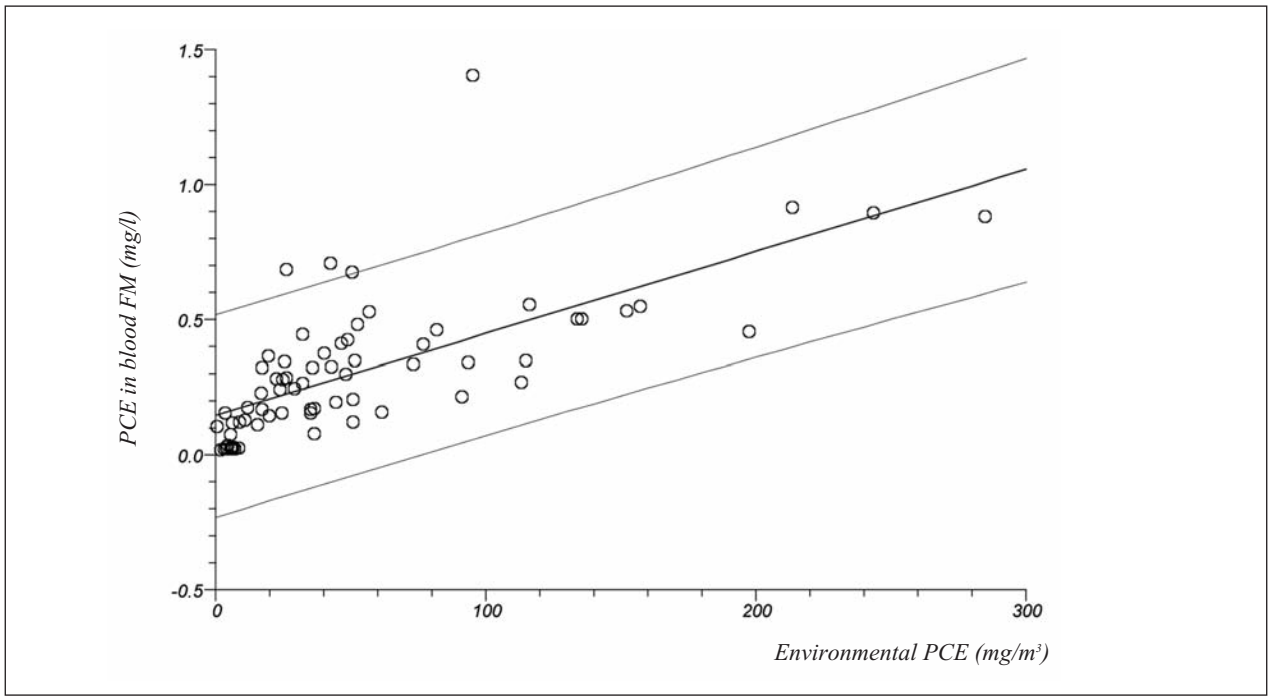

Figure 2 - Correlation between PCE in blood (mg/l) on Friday morning (FM) and environmental exposure to PCE (mg/m^3)

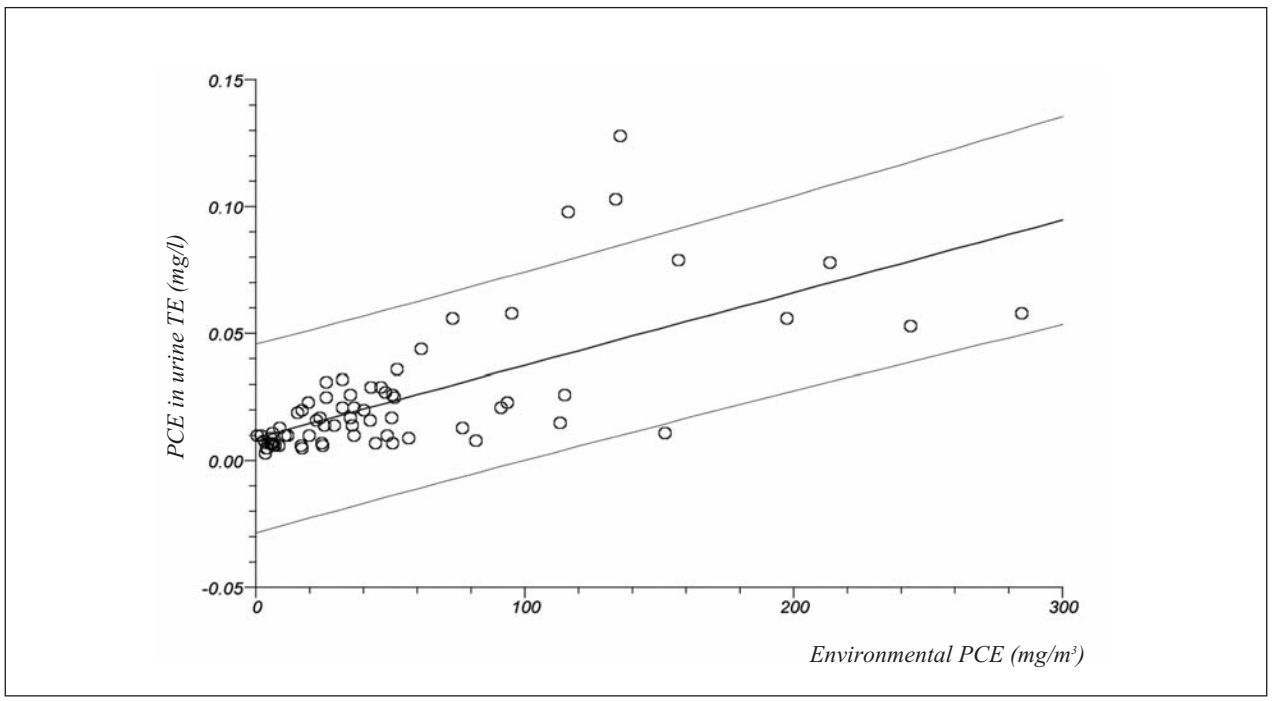

Figure 3 - Correlation between PCE in urine (mg/l) on Thursday evening (TE) and environmental exposure to PCE (mg/m^3)

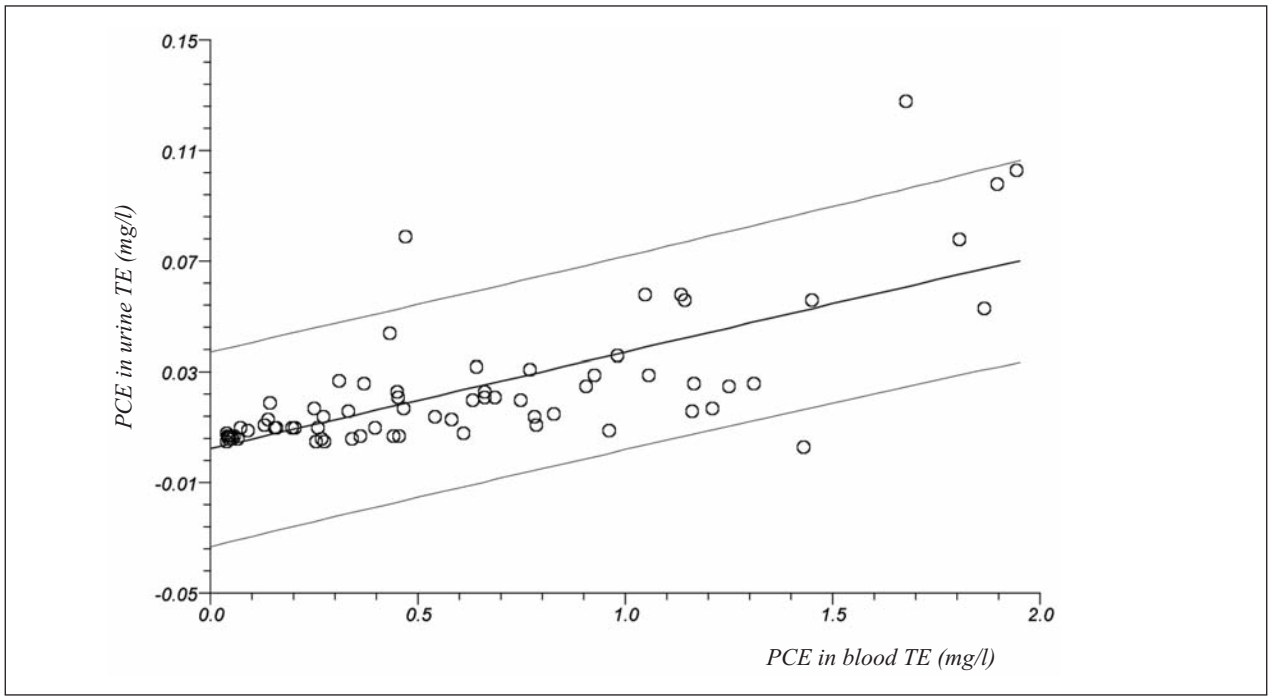

Figure 4 - Correlation between PCE in blood (mg/l) and in urine (mg/l) on Thursday evening (TE)

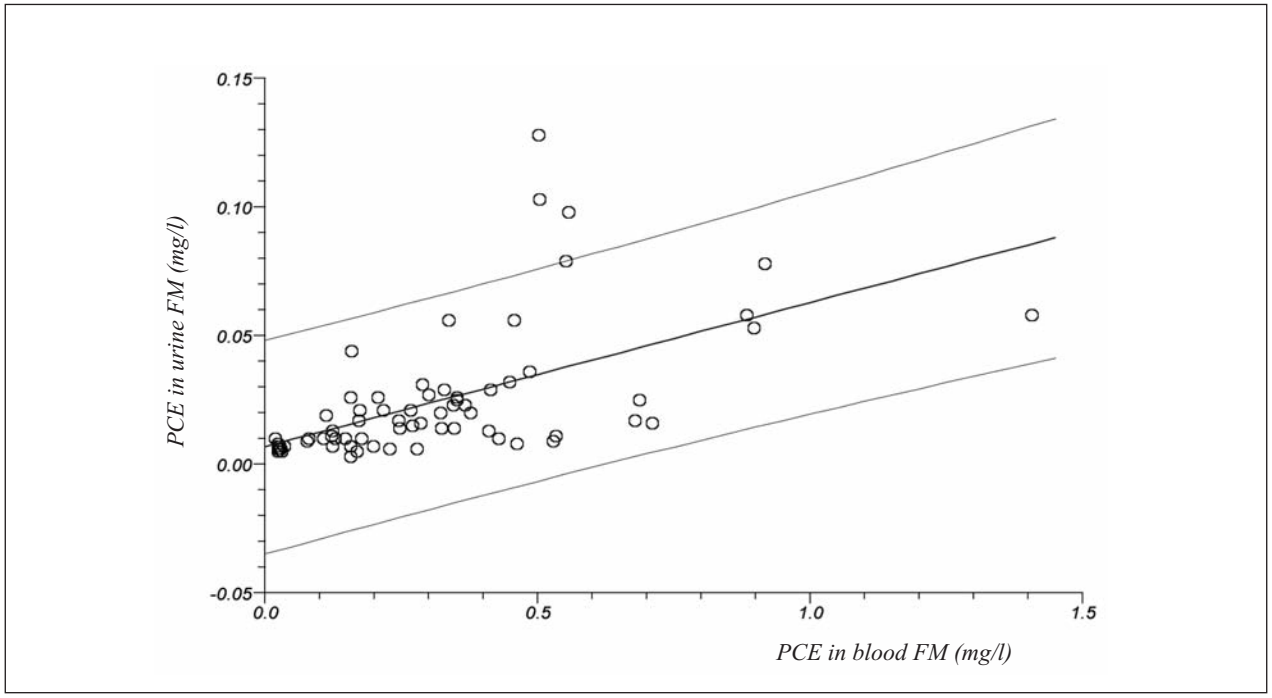

Figure 5 - Correlation between PCE in blood (mg/l) on Friday morning (FM) and in urine (mg/l) on Thursday evening (TE)

correlations were found between PCE in blood and in urine on Thurday evening (r=0.72), PCE in blood on Friday morning, and PCE in urine on Thursday evening, although the correlation coefficient was lower (r=0.58).

Discussion

The results of this study show that occupational exposure to PCE in dry cleaning shops is moderate (about 30% of the present ACGIH TLV-TWA), matching the current tendency to reduce exposure, as reported in other Italian (1, 9, 10) and international studies (8, 18, 32). A systematic review of the American literature (11) on all studies from 1936 to 2001 reveals high exposure level (on average 387.6 mg/m^3 or 57 ppm) with values exceeding 890 mg/m^3 (131 ppm) for short operations (<1 h), but 102 mg/m^3 for exposure exceeding 6 h. However, considering the last ten-year period (1990-2001), the mean exposure value was found to be 68 mg/m^3 (10.02 ppm). One study performed in Teheran (3) examining 69 dry cleaners found a mean value of 11.5 ppm for workers loading and unloading the machines. The value was lower, although the difference was not significant, for exposure in the ironing room (9.6 ppm) and near the counter, where clothes are accepted for cleaning and later returned to customers (7.2 ppm).

A recent study in several Scandinavian countries (16) examined 1296 environmental PCE measurements in dry cleaners in Denmark, Finland, Norway and Sweden between 1947 and 2001. The study found a quite stable exposure trend in all four countries between 1947 and 1976, with a mean value of about 20 ppm, later falling to 3 ppm until 2000.

The data analyzed according to number of employees and shop size show that small, family-run laundries and with few employees are more contaminated than larger ones with more employees. In dry cleaning shops with less than 3 employees, the majority (25% of cases) exceeded the PCE threshold in blood and about 8% the environmental threshold. In shops with more staff, no environmental and biological threshold was exceeded. The importance of shop size is confirmed by the fact that PCE in air, blood and urine were higher in small shops and the values decreased according to the increasing shop size.

It should be emphasized that no dry cleaning shop had special systems for air ventilation or aspiration, and that the lowest exposure values were due to dilution of PCE in the environment.

The manual operations of machine opening and closing posed the highest risk because the PCE concentrations usually exceeded 100 ppm. However, the peaks did not last long, as already 5 min after the end of unloading the level of environmental PCE fell to 35 ppm. The results show that PCE exposure due to these manual operations, in relation of the number of cleaning cycles (3-4 per day), the time of opening and unloading (10-15 minutes for each cleaning cycle) and the PCE levels measured with colorimetric tubes, is on average comparable to TLV-STEL. Actual cleaning operations, sometimes carried out with PCE, led to lower pollution peaks, never exceeding 50 ppm (maximum value 40 ppm) and always rapidly fell (to 6 ppm after 5 min). Gold et al. (11) reported high exposure, around 300 ppm, during filter changing in an industrial dry cleaning plant. According to Lynge et al. (16), measurements taken from area samplers show higher values than personal samplers (11.92 ppm vs 7.27 ppm) and maintenance operations on machines lead to greater mean concentrations (35.94 ppm) than in workers who merely operate the machines (13.20 ppm) and in shop assistants (7.50 ppm).

Statistically significant correlations were found between concentrations of PCE in air and blood, both on Friday morning (according to ACGIH recommendations for sampling) and Thursday evening (sampling 15 to 30 min after end-of-shift), with respective r values of 0.70 and 0.67, confirming the good reliability of this biological marker. A significant correlation between PCE in air and blood collected at end-of-shift and at the end of the working week was also demonstrated by Furuky et al. (8) with r=0.77 (n=51). Gobba et al. (9) also found a good correlation between PCE in air and blood at end-of-shift, with r=0.94, although in a small number of subjects (n=20). A statistically significant correlation between Thursday morning

PCE in blood and environmental PCE on Wednesdays was obtained by McKernan et al. (18). The comparison of mean PCE values in blood on Thursday evening (0.617 mg/l) and Friday morning (0.304 mg/l), i.e. after at least 12 h, confirms that t1/2 in the first kinetic phases of elimination of PCE is 12-16 h, as reported by Monster et al. (19, 20).

The 0.660 mg/l value of PCE in pre-shift blood on Friday morning calculated in our study, corresponding on average to a PCE exposure of 170 mg/m^3, is close to the BEI adopted by ACGIH (2). This marker, which is not usually found in significant concentrations in non-occupationally exposed subjects, is a highly specific indicator of exposure (8, 18). However, its measurement requires a more invasive method than urine collection.

The correlation between PCE exposure and PCE in urine was good and statistically significant, but only on Thursday evening (r=0.68), confirming how collection at end-of-shift gives a weighted value representing exposure to the solvent throughout the period during which the urine formed (10). Similar correlations were also reported by Gobba et al. (9) (r=0.67 in 26 subjects) and Furuki et al. (8) (r=0.77 in 54 subjects). Imbriani et al. (13) reported a better correlation, with r=0.86 in a higher number of 335 subjects. PCE was absent in the urine of subjects not exposed to significant concentrations: in a sample of 50 subjects, urinary PCE values were in the order of ng/l, with a median value of 22 ng/l (standard deviation 3.0 ng/l) (12). In addition, the value of PCE in end-of-shift urine of 0.058 mg/l calculated in our study as corresponding on average to a PCE exposure of 170 mg/m^3 in quite similar to the value of 56 μg/l proposed by Imbriani et al. (13).

As regards urinary TCA, correlations with environmental data on both Thursday evening and Friday morning were not significant. There are several reasons for the lack of correlation: urinary TCA increases during the working week by a factor of 2 with respect to Monday (12, 20) and, at the beginning of the following week, the concentration returns to the starting values. Urinary TCA appears to be an index of overall exposure, whereas the environmental value only refers to one working day. Droz and Fernandez (7) found a good correlation between urinary TCA after 2 non-working days (Monday) and extent of exposure measured during the preceding working week, whereas McKernan et al. (18) did not recommend using this metabolite because of its extreme variability. In addition, TCA is a non-specific biomarker, being an important metabolite of other chloride compounds, like trichloroethylene and methyl chloroform which is widely used in household cleaning products. In particular, trichloroethylene is also used to manually remove stains in dry cleaning shops and may be present as an impurity in PCE solvent. The analyses carried out during our study on PCE from three different shops and used by several dry cleaners monitored revealed the presence of a non-negligible percentage of trichloroethylene as an impurity. Lastly, it is known that metabolism to TCA is the main metabolic pathway of trichloroethylene whereas a small amount of PCE is metabolized to TCA, which correlates poorly at low exposures (10, 20, 23, 26, 27). These reasons justify our results; on the other hand, the values of TCA found in dry cleaning workers were on average greater than the BEI ACGIH of 3.5 mg/l proposed until 2008. In addition, these aspects of non-specificity and ambiguity explain why the ACGIH has excluded the use of urinary TCA as a marker of biological monitoring since 2009.

The statistically significant correlation between PCE in blood and in urine at end-of-shift (r=0.72, $p < 0.001$) (figure 4) confirms the validity of PCE of end-of-shift blood as biomarker of exposure; a good correlation between PCE in blood and in urine at end-of-shift was also shown by Gobba et al. (9), with r=0.95 in 20 subjects, and Furuky et al. (8), with r=0.71 in 50 subjects. It must be noted that, based on our data, concentrations of PCE in end-of-shift blood corresponds to an exposure of 170 mg/m^3 and is almost double (1.308 mg/l) that of PCE in pre-shift blood (0.660 mg/l).

In conclusion, this study shows that dry cleaners are subject to conditions of exposure and pollution by PCE, although to a lesser extent than in the past. However, the values may still be non-negligible and exceed the threshold limit values adopted by international organizations.

Biological monitoring is confirmed as an excellent procedure for assessing individual worker's exposure: the most reliable markers are PCE in end-of-shift urine and PCE in blood at end-of-shift and pre-shift at the end of the workweek.

NO POTENTIAL CONFLICT OF INTEREST RELEVANT TO THIS ARTICLE WAS REPORTED

REFERENCES

1. Agazzotti G, Fantuzzi G, Righi E, et al: Occupational and environmental exposure to perchloroethylene (PCE) in dry cleaners and in their family members. Arch Environ Health 1994; *49*: 487-493
2. American Conference of Governmental Industrial Hygienists (ACGIH): *2011 TLVs and BEIs. Threshold limit values for chemical substances and physical agents and biological exposure indices.* Cincinnati, Ohio, 2011
3. Azimi Pirsaraei SR, Khavanin A, Asilian H, Soleimanian A: Occupational exposure to percholoroethylene in dry cleaning shops in Tehran, Iran. Ind Health 2009; *47*: 155-159
4. Cavalleri A, Gobba F: Effetti tossici e sorveglianza sanitaria dell'esposizione occupazionale a percloroetilene nelle lavanderie a secco. In Cavalleri A: *Lavanderie a secco: rivalutazione del rischio da solventi*. Quad Med Lav Med Riab. Pavia: Tipografia PI-ME Editrice, 1994: 73-94
5. Cocheo V, Boaretto C, Sacco P: High uptake rate radial diffusive sampler suitable for both solvent and thermal desorption. Am Ind Hyg Assoc J 1996; *57*: 897-904
6. Christensen JM, Rasmussen K, Koppen B. Automatic headspace gas chromatographic method for the stimulateous determination of trichloroethylene and metabolites in blood and urine. Journal of Chromatography 1988; *442*: 317-323
7. Droz PO, Fernandez JG: Trichloroethylene exposure. Biological monitoring by breath and urine analyses. Br J Ind Med 1978; *35*: 35-42
8. Furuki K, Ukai H, Okamoto S, et al: Monitoring of occupational exposure to tetrachloroethene by analysis for unmetabolized tetrachloroethene in blood and urine in comparison with urinalysis for trichloroacetic acid. Int Arch Occup Environ Health 2000; *73*: 221-227
9. Gobba FG, Righi E., Fantuzzi G, et al: Perchloroethylene in alveolar air, blood, and urine as biologic indices of low-level exposure. J Occup Environ Med 2003; *45*: 1152-1157
10. Gobba F, Rosa P, Ghittori S, et al: Environmental and biological monitoring of occupational exposure to perchloroethylene in dry clearing shops. Med Lav 1997; *88*: 24-36
11. Gold LS, De Roos AJ, Waters M, Stewart P: Systematic literature review of uses and levels of occupational exposure to tetrachloroethylene. J Occup Environ Hyg 2008; *5*: 807-839
12. Imbriani M. Valutazione critica degli indicatori di dose interna nella esposizione occupazionale a perclorotetilene. In Cavalleri A: *Lavanderie a secco: rivalutazione del rischio da solventi*. Quad Med Lav Med Riab. Pavia: Tipografia PI-ME Editrice, 1994: 41-62
13. Imbriani M, Ghittori S, Pezzagno G, Capodaglio E: Urinary excretion of tetrachloroethylene (percloroethylene) in experimental and occupational exposure. Arch Environ Health 1988; *43*: 292-297
14. International Agency for Research on Cancer (IARC): *Dry cleaning, some chlorinated solvents and other industrial chemicals*. Monographs on evaluation of the carcinogenetic risk to chemicals to humans. Vol. 63. Lyon: IARC, 1995
15. Ling S, Lindsay WA: Perchloroethylene Burns. Br Med J 1971; *3*: 115
16. Lynge E, Tinnerberg H, Rylander L, et al: Exposure to tetrachloroehylene in dry cleaning shops in the nordic countries. Ann Occup Hyg 2011; *55*: 387-396
17. Materna BL: Occupational exposure to perchloroethylene in the dry cleaning industry. Am Ind Hyg Assoc J 1985; *46*: 268-273
18. McKernan LT, Ruder AM, Petersen MR, et al: Biological exposure assessment to tetrachloroehylene for workers in the dry cleaning industry. Environ Health 2008; *7*: 12
19. Monster AC, Boersma G, Steenweg H: Kinetics of tetrachloroethylene in volunteers; influence of work load and exposure concentration and work load. Int Arch Occup Environ Health 1979; *42*: 303-309
20. Monster A, Regouin-Peeters W, Van Schijndel A, Van der Tuin J: Biological monitoring of occupational exposure to tetrachloroethene. Scand J Work Environ Health 1983; *9*: 273-281
21. Morgan B: Dangers of perchloroethylene Br Med J 1969; *2*: 513
22. National Cancer Institute: *Bioassay of tetrachloroethylene for possible carcinogenicity*. HEW Publication 1977; 77-813: 1-19
23. Popp W, Muller G, Baltes-Schmitz B, et al: Concentrations of tetrachloroethene in blood and trichloroacetic acid in urine in workers and neighbours of dry cleaning shops. Int Arch Occup Environ Health 1992; *63*: 393-395
24. Selis L, Ferroni C, Mutti A, et: al. Effetti neurocomportamentali dell'esposizione professionale a percloroe-

tilene. Atti del *52° Congresso Nazionale della Società Italiana di Medicina del Lavoro ed Igiene Industriale*. Palermo 28/09-1/10/1989: 161-165

25. Senft V. Simple determination of trichloroacetic acid in urine head space gas chromatography: a suitable method for monitoring exposure to trichloroethylene. Journal of Chromatography 1985; *337*: 126-130
26. Skender LJ, Karacic V, Bosner B, Prpic-Majic D: Assessment of urban population exposure to trichloroethylene and tetrachloroethylene by means of biological monitoring. Arch Environ Health 1994; *49*: 445-451
27. Skender LJ, Karacic V, Prpic-Majic D: A comparative study of human levels of trichloroethylene and tetrachloroethylene after occupational exposure. Arch Environ Health 1991; *46*: 174-178
28. Solet D, Robins TG: Renal function in dry cleaning workers exposed to perchloroethylene. Am J Ind Med 1991; *20*: 601-614
29 .Spencer PS, Schaumburg HH: Organic solvent neurotoxicity. Facts and research needs. Scand J Work Environ Health 1985; *11* (Suppl 1): 53-60
30. Stewart RD, Baretta ED, Dodd HC, Torkelson TR: Experimental human exposure to tetrachloroethylene. Arch Environ Health 1970; *20*: 225-229
31. Trevisan A, Maccà I, Rui F, et al: Kidney and liver biomarkers in female dry-cleaning workers exposed to perchloroethylene. Biomarkers 2000; *5*: 399-409
32. Von Grote J, Hurlimann C, Sheringer M, Hungerbuhler K: Assessing occupational exposure to perchloroethylene in dry cleaning. J Occup Environ Hyg 2006; *3*: 606-619